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On the life time of contrail cirrus

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Contrails represent reproducible prototypes of cirrus clouds which are easier to understand scientifically and offer better chances for experimental investigations than natural cirrus. In the past, investigation of contrails led to important general insight into the atmosphere system, such as the detection of ice supersaturation, homogeneous and heterogeneous ice particle formation, and subvisible cirrus. Even the Brewer-Dobson circulation was detected because contrails were observed to be short-lived at multitudes above the tropopause.

Here we present results constraining the mean life time of contrail cirrus based on comparisons of results from a new contrail cirrus model, ECMWF forecast data and several years of Meteosat satellite observations for the North Atlantic and Europe.

The mean life time of contrails is not yet well known. Persistent contrails form at aviation cruise altitudes mainly in the upper troposphere, when the temperature is below the Schmidt-Appleman (SAC) threshold temperature and when the ambient atmosphere is humid enough for long-lived contrails. The SAC threshold depends on aircraft and fuel properties, pressure and humidity. Contrails spread and persist in ice supersaturated air masses. Contrails are visible also for several minutes or even longer when the relative humidity is slightly below saturation, in particular at low temperatures. Contrails survive until the ambient air gets dried beyond ice saturation (e.g. by subsidence, mixing with dry air, radiative warming) or until the ice particles get large enough to sediment quickly and to fall down into drier air masses or, rarely, precipitate to ground. Contrails with large ice particles may end in fallstreaks (i.e. in a curtain of large and quickly falling ice particles). With time, contrails may loose their identity and become part of other thicker cirrus clouds.

We model the formation and decay of contrails for a fleet of aircraft using a recently developed Lagrangian contrail cirrus prediction model CoCiP (Schumann, U.: A contrail cirrus prediction model, Geosci. Model Dev. Discuss., 4, 3185-3293, doi:10.5194/gmdd-4-3185-2011, 2011). The formation of contrails and their transition into contrail cirrus is modeled for given aircraft types, aircraft tracks and given meteorology (taken from ECMWF). We found that the computed contrail cover is highly sensitive to the processes which limit the life time of contrail cirrus.

The life-time of contrail clusters should be similar to the lifetime of ice supersaturated regions (ISSR) which has been estimated at mid-latitudes to vary from minutes to possibly a few days with median values of order hours. Here, we estimate the life-time of ISSR regions by computing the age of trajectories which start at aircraft waypoints satisfying the SAC in ice supersaturated air and last until the ambient humidity drops below ice saturation. This aircraft-related ISSR-life-time is not the life-time of ISSR per se, but the life-time of ice supersaturation relevant for contrails. For this purpose we use the Lagrangian trajectory model part of CoCiP for a passive tracer with ECMWF data. Most of such trajectories end after less than one hour. The age frequency distribution follows an exponential function. Based on such a fit the mean and median ages of ISSR regions are 14.6 and 10.1 h. The life time depends on many parameters; it is large in particular in the upper and mid polar and upper tropical troposphere.

When we apply CoCiP for contrails including ice formation form ambient ice supersaturation but without any particle number loss process, we compute ages which exceed the ISSR ages. The larger life time result from the reservoir of ice water built up in the contrails while staying in the ISSR. This ice water reservoir is a maximum just when the ISSR regime ends. It takes considerable time to mix drier ambient air into the contrail and to sublimate this ice. Hence, the total contrail age without ice loss processes could reach about 1.5 times the age of ISSR masses. With some loss processes included in the model, the contrail life time is smaller than that of ISSR. In this example, the mean and median ages for this June-case are 3 h and 2 h, respectively. Hence, the life time of contrail cirrus depends strongly on ice particle loss processes. So far, we use rather crude models to simulate these losses. These models are heavily dependent on suitable observations data.

As a test case for our model we consider the diurnal cycle of cirrus over a region in the North Atlantic air traffic domain. The observational data used are the cover of cirrus and the outgoing longwave radiation (OLR) at top of the atmosphere. This situation is modeled using ECMWF data for background cirrus. CoCiP is used to simulate the contrails cirrus cover and its impact on OLR. Comparisons of the CoCiP simulation results of diurnal cycle of cirrus properties show that the median life time of contrail cirrus in these regions of about 2 to 3 hours. This result has strong impact on the climate impact of contrails. Further investigations are needed to refine the modeling of cirrus and contrail cirrus decay.